

PRV

PATENT- OCH REGISTRERINGSVERKET
Patentavdelningen



Intyg Certificate

Härmed intygas att bifogade kopior överensstämmer med de handlingar som ursprungligen ingivits till Patent- och registreringsverket i nedannämnda ansökan.

This is to certify that the annexed is a true copy of the documents as originally filed with the Patent- and Registration Office in connection with the following patent application.

SE 00/D1522

(71) Sökande NanoLight International Ltd, Anieres CH
Applicant (s)

(21) Patentansökningsnummer 9903226-0
Patent application number

(86) Ingivningsdatum 1999-09-10
Date of filing

(30) Prioritet begärd från 1999-07-30 SE 9902823-5

Stockholm, 2000-09-13

För Patent- och registreringsverket
For the Patent- and Registration Office

Åsa Dahlberg
Åsa Dahlberg

Avgift
Fee

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN
COMPLIANCE WITH RULE 17.1(a) OR (b)

PATENT- OCH
REGISTRERINGSVERKET
SWEDEN

Postadress/Adress
Box 5055
S-102 42 STOCKHOLM

Telefon/Phone
+46 8 782 25 00
Vx 08-782 25 00

Telex
17978
PATOREG S

Telefax
+46 8 666 02 86
08-666 02 86

A LIGHT SOURCE, AND A FIELD EMISSION CATHODE.

5 FIELD OF THE INVENTION

The present invention relates to a light source according to
~~the introductory portion of claim 1, especially a light source~~
for illumination. Further, the present invention relates to a
field emission cathode according to the introductory portion
10 of claim 21.

BACKGROUND OF THE INVENTION

One common type of light sources is the fluorescent tube. It
15 has many advantages, but suffers from serious drawbacks. For
example, there is always a delay after the power has been
turned on until it starts to operate giving full light. It
needs complicated control equipment, which requires space. To
obtain light with a source of this kind it is unfortunately
20 necessary to use materials having negative environmental
effects. It is for example a big disadvantage that mercury has
to be used in this type of light sources.

Cathodoluminescent light sources is another interesting type
25 of light sources. Such light sources, including an evacuated
envelope containing a grid and a heated cathode, for emission
of electrons, are known from GB, A, 2 070 849 (The General
Electric Company Limited), GB, A, 2 097 181 (The General
Electric Company PLC), GB, A, 2 126 006 (The General Electric
30 Company plc) and GB, A, 2 089 561 (The General Electric
Company Limited). The insides of the envelopes are covered
with a layer of phosphor of an electron-responsive type. These
cathodoluminescent lamps have essentially the form of an
electric bulb.

35

Since these light sources all have a heated cathode, the cathode has to be heated by special means, before the emission of light starts.

5 The use of electrons exciting phosphor to luminescence has the effect that more heat is produced than in comparable
fluorescent tubes. It is therefore advantageous if the active
surface, for the emission of light and for the necessary heat
dissipation, is large. The cathodoluminescent lamps shown in
10 the documents mentioned do not have optimal surfaces.

To overcome the drawbacks and problems with the fluorescent tubes and cathodoluminescent light sources, light sources having field emission cathodes were developed.

15 A light source of this kind is disclosed in US, A, 5 588 893 (Kentucky Research and Investment Company Limited). A field emission cathode is arranged inside an evacuated glass container having a luminescent layer arranged on its inner
20 surface. A modulator or extraction electrode is provided between the cathode and the luminescent layer. The cathode includes carbon fibres, arranged in bundles, preferably in a matrix, on a substrate. The content of US, A, 5 588 893 is incorporated herein by reference.

25 However in the last-mentioned known light source, electrons are emitted only in a direction perpendicular to the substrate. Also, there is no indication in the document how to produce the light source in a cost-efficient way.

30 The above mentioned US, A, 5 588 893 (Kentucky Research and Investment Company Limited) also discloses a field emission cathode of the kind mentioned above. The cathode disclosed includes carbon fibres, arranged in bundles, preferably in a
35 matrix, on a substrate. The document also discloses a method

including treatment of the emitting surfaces in order to achieve a cathode with higher efficiency than previous cathodes.

5 Further, WO, A1, 98/57344 (LightLab AB) and WO, A1, 98/57345 (LightLab AB) disclose light sources having cylindrical geometry and employing field emission. In order to obtain the necessary electric field for field emission, the mentioned light sources include grids or modulator electrodes arranged
10 close to the field emitting surfaces of the cathodes. In those light sources a relatively high electric field has to be created between the cathode and the grid, and the distance between the field emitting surfaces and the grid has to be small and uniform in order to achieve a sufficient electric
15 field for field emission and good distribution of electrons emitted from the cathode.

A further document, WO, A1, 97/07531 (Silzars et. al.) discloses a lighting apparatus including a field emission
20 cathode. The cathode is built up of one or more fibers. The fibers are very thin, having a diameter less than 100 microns, and preferably less than 10 microns. The diameters are selected in order to achieve field emission at reasonable voltages. A construction according to this document having one
25 fiber will be inoperative if the fiber is broken. Since the fiber is very thin, the probability of that it breaks appears to be high. However, the probability is probably somewhat lowered by arranging more than one fiber in parallel, for redundancy. Moreover, the electron emission surface is very
30 small due to the small diameter of the fiber(s).

Previously known field emission cathodes are often of a complicated and fragile construction, especially as concerns the mountings and the attachment of field emitting bodies.
35

It has been found in connection with cathodes including standard carbon fibers and a grid that the electrical fields acting between the cathode and a grid or an anode can cause individual fibers to get loose from their carrier if they are not safely secured thereto. Once loose, the fibers will, in most cases, be attracted by the grid and cause a short circuit between the cathode and the grid, until it burns off after some time due to the resulting current through the fibres.

10 SUMMARY OF THE INVENTION

It is an object of the invention to provide a light source and a field emission cathode, respectively, providing a concentrated electric field at the field emission surface(s), and by which at least some of the drawbacks above are eliminated or reduced.

These and other objects are attained by the features set forth in the appended independent claims.

20

By the features in claims 1 and 21, it is achieved a light source and a field emission cathode, respectively, having a long life, with high efficiency and stability, which can be produced at low cost.

25

By the features in claims 1 and 21, it is achieved a light source and a field emission cathode, respectively, having a sufficient electric field for field emission with good distribution and high emission of electrons from the cathode.

30

By the features in claims 1 and 21, it is also achieved a light source and a field emission cathode, respectively, in which field emission can be obtained without the use of a grid or extraction electrode.

35

By the features in claim 1, further, a light source without a starting up period is achieved, i.e. when the power is turned on, the light starts immediately, thanks to the use of a field emission cathode. A light source with no need for materials having negative environmental effects is also achieved.

By the features in claim 1, further, a light source having a field emitting cathode of simple and robust construction is obtained.

By the features in claim 5, further, a light source having a large active light emitting surface is achieved. This efficient use of the surface renders it possible to achieve a light source having a high light emission in relation to the heat produced.

By the features in claim 2', further, a field emitting cathode of simple and robust construction is obtained.

By the features in claims 2' through 33, a field emitting cathode is obtained which further provides for a high emission and uniform distribution of emitted electrons, in particular through a cylindrical surface region surrounding the cathode. A cathode with low interference between the field emitting surfaces is also achieved.

Further features and advantages will be apparent from the dependent claims and the detailed description below.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows schematically a longitudinal section of an embodiment of a light source according to the present invention,

GA



Fig. 2 shows schematically a cross section taken at II-II in Fig. 1,

5 Fig. 3 shows schematically the cathode and the anode of Figure 2,

10 ~~Fig. 4 shows schematically a cross section of an alternative embodiment of a light source according to the present invention,~~

Fig. 5 shows schematically a cross section of a further alternative embodiment of a light source according to the present invention,

15 Fig. 6 shows schematically a cross section of a yet further alternative embodiment of a light source according to the present invention, and

20 Fig. 7 shows schematically a possible shape of a light source according to the present invention.

6B
J

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100

Fig. 2 shows schematically a cross section taken at II-II in Fig. 1,

5 Fig. 3 shows schematically the cathode and the anode of Figure 2, and

10 Fig. 4 shows schematically a cross section of an alternative embodiment of a light source according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

15 Referring to figure 1, there is shown, in a schematic longitudinal section, an embodiment of a light source according to the present invention, identified generally by the numeral 10, and especially intended for illumination purposes. It includes a container having walls, one of which is identified by the numeral 20. This wall 20 has an outer glass layer and is shown to be cylindrical. The cylinder 20 has an end 21 which is covered by an end cap 60. A sealing (not shown) is provided between the end cap and the cylinder 20, in order to achieve an air-tight sealing of the container. At the other end 22 of the cylinder 20 an end cap 61 is provided, similar to the one arranged at the end 21, also provided with a sealing. Alternatively, at the end 22 there can be arranged a circular wall as a continuation of the cylinder wall 20, also having an outer layer of glass. The container is sealed in order to maintain the vacuum (approximately 10^{-6} torr) created when the container is evacuated.

Inside the container and preferably coaxially therewith, a cathode 40 is arranged. This cathode is a cold cathode,

7
↑

especially a field emission cathode. Its construction and function will be explained further below.

The light source is provided with electrical connections 51, 52, and means (not shown) for fastening of the cathode 40. The cathode 40 can be soldered to the caps 60, 61 or it can be adhered to the caps 60, 61 by an adhesive, preferably an electrically conducting adhesive. It could also be clamped to the caps 60, 61 by clamping means or gripped by gripping means. It is also possible that a circular wall, which is a continuation of the cylinder wall 20, is provided with supporting, fastening or gripping means.

The cylindrical part 20 of the container walls surrounding the cathode 40 consists of an outer glass layer 23, a phosphor layer 24 (a cathodoluminescent phosphor) and an inner conductive layer 25 forming an anode. The phosphor layer is a luminescent layer which upon electron bombardment emits visible light. The anode is preferably made of a reflecting, electrically conductive material, e.g. aluminium. By arranging an aluminium layer covering the phosphor layer, adverse effects on the vacuum by possible evaporation of the phosphor are avoided.

The electrical connection means 51, 52 connect the cathode 40 and the anode 25, respectively, to a feed and control circuit (not shown). Those connection means preferably include conductive terminal pins which extend through the cap 60 and are insulated from each other. The electrical connection means 52 could further include conductive fingers or similar, which are in contact with the anode layer 25 provided inside the container. The openings for the electrical connection means 51, 52 in the end cap 60 are air-tight sealed. At the other end 22 of the container wall 20, there can be arranged an end cap 61 similar to the end cap 60, to support the cathode 40.

However, this end cap 61, at the other end 22, could be formed without electrical connection means.

The cathode 40 includes a relatively thin wire or rod, of electrically conductive material, e.g. a nickel wire. The wire or rod preferably has a circular cross section and its diameter is in the millimeter range, about one to a few mm, e.g. 0.5-5mm or 1.5-2mm. This provides for a strong and durable cathode, exhibiting a surface sufficient for a high emission of electrons. The area of the wire is also sufficient for the current to be conducted therethrough.

Figure 2 shows the light source of Figure 1 in a cross section taken at II-II.

In operation, a DC voltage is supplied between the cathode 40 and the anode 25 by means of a feed and control circuit (not shown), which could be located in a housing, connected to the AC mains e.g. through an ordinary lamp socket. The feed and control circuit supplies the voltages to the conductive terminal connections 51-52, to which it is connected. Preferably connection 52 is at ground potential and connection 51 is negative. When the voltage is applied, an electrical field is created between the cathode 40 and the anode 25.

Due to the geometry of the light source according to the invention a favourable distribution of the electric field is obtained. The electric field is strongest where a strong electric field is needed, for obtaining field emission, namely around the cathode. The following formula gives the electric field strength in a structure according the invention, having a central conductor coaxially surrounded by a circular cylindrical conductor:

$$E(r) = \frac{V_0}{\ln \frac{R_o}{R_i}} \cdot \frac{1}{r}, \text{ where } E(r) \text{ is the electric field strength at}$$

radius r with respect to the central axis of the central conductor, V_0 is the voltage applied between the conductors (cathode and anode in the light source), R_o is the inner radius of the cylindrical conductor (the anode) and R_i is the outer radius of the inner conductor (the cathode). In Figure 3, which schematically shows the cathode and the anode of Figure 2, variables of the formula are indicated. As seen from the formula a very strong electric field close to the cathode can be obtained with suitably selected dimensions. Especially a small radius of the cathode (small r) will give a high electric field close to the cathode. The electric field lines will be concentrated around the cathode, and it can be seen as if the cathode were surrounded by a virtual extraction electrode.

In order to obtain field emission from the cathode, it is covered with a field emitting material, such as a layer of carbon nanotubes. The electric field is then further amplified around the field emitting tips, and an amplification factor (of the field) of 1000 and even more can be obtained. This can be seen as an amplification of the effect of said virtual extraction electrode. Taking this amplification factor (about 1000) into account, the electric field needed to efficiently extract electrons (by field emission) from a layer of nanotubes is about 1 kV/mm.

For further explanation and discussion of nanotubes it is referred to the articles "Field emission from carbon nanotubes: a comparative study" by J M Bonard, J P Salvetat, T Stöckli, L Forró, A Châtelain, Proceedings of the 193rd ECS symposium, 1998, and "Field emission properties of multiwalled carbon nanotubes" by J M Bonard, F Maier, T Stöckli, A Châtelain, W A de Heer, J P Salvetat, L Forró, Ultramicroscopy

73 (1998) 7-15, which articles are incorporated herein by reference.

The irregularities are formed by carbon nanotubes applied on the (cylindrical) surface of the wire or rod included in the cathode. The nanotubes have a very short length, less than about 10 μm , and do not affect the variable r in the formula since the diameter of the wire or rod of the cathode is selected in the mm range, about one to a few mm, e.g. 0.5-5 mm or 1.5-2 mm. The tips of the nanotubes have a radius of curvature being in the range 0.1-100 nanometers.

The applied carbon nanotubes can be of different types, e.g. single wall nanotubes or open or closed multi wall nanotubes. In this case catalytically deposited multi wall nanotubes deposited in the form of a film are suitable and can be applied by a simple process. Such nanotubes are suitable for depositing on a wire and they will be appropriately oriented by the process, with their respective longitudinal axis being essentially perpendicular to the longitudinal axis of the wire. Further, application of nanotubes by a catalytic or alternatively CVD process results in good uniformity and low manufacturing cost. Recent laboratory measurements confirm that the amplification factor is about 1000 in catalytically deposited nanotube films and that currents up to 10 mA/cm^2 are obtained.

When the field strength is sufficient to cause field emission of electrons from the field emitting surfaces (tips) of the field emitting material (nanotubes) of the cathode 40, the electrons will accelerate and travel towards the anode 25. Due to the high kinetic energy of the electrons and the fact that the anode layer is relatively thin (*less than 0.1 micron*), the electrons will pass through the anode so as to enter the phosphor layer while still having sufficient kinetic

energy to excite the phosphor to luminescence, whereby visible light is emitted. The electrons will then return to the anode to be drained off. The electron bombardment will cause, besides light, heating of the cylinder wall 20. The glass layer will provide for the dissipation of the heat. The voltage is in the range of kV, typically about 4-8 kV. The voltage much depends on the type of phosphor used. New types of phosphor are continuously developed and because of that, the voltage must be adapted to the specific type of phosphor used. Changing the type of phosphor and thereby the voltages will cause changes in the currents and the heating of the cylinder wall.

If for example a phosphor layer 24 which needs to be bombarded with electrons of about 8 kV in order to obtain a good efficiency, and the cathode 40 has a diameter of about 1 mm in order to assure that the nanotube layer has a sufficiently big surface to emit the current needed for high light intensity, the above formula gives an electric field of 4 kV/mm at the cathode surface with an inner diameter of the anode 25 being 55 mm. With a cathode diameter of 1.5 mm, 3.9 kV/mm is obtained at the cathode surface if the inner diameter of the anode 25 is 28 mm. A field strength of about 4 kV/mm has been chosen in these examples to be safely above the 1 kV/mm needed.

For the example above with a cathode diameter of 1.5 mm and an inner diameter of the anode being 28 mm, a length of 20 mm (anode and cathode) gives an electron emission surface of about 1 cm². From this surface electrons corresponding to a current of 10 mA can be emitted. The corresponding phosphor surface is about 20 cm², which thus gives a current density of 0.5 mA/cm² at the phosphor surface. This is a too high density for continuous operation (for a high voltage of 8 kV, this corresponds to 80 W for a 20 mm long cylinder lamp).

With a light source according to the invention there is thus no problem to obtain currents, and consequently light intensities well corresponding to what is obtained from a classical fluorescent light tube. As seen from the examples the outer diameter of a light source according to the invention can be made to correspond well to that of a classical fluorescent light tube. As apparent from the description, the light source according to the invention starts to emit light immediately, when a voltage is applied between the anode and the cathode.

Due to the geometry of the light source according to the invention, the dimensional tolerances ~~(do not have)~~ are not required to be very exact, especially in comparison to light sources having a grid. This is apparent from the formula above, and contributes to low manufacturing costs.

Figure 4 shows an alternative embodiment of a light source, according to the invention, in cross section. What differs from fig. 2 is the arrangement of the layers of the wall 20'. It includes an outer glass layer 23', which is covered, on at least a major part of its inside, by an electrically conductive transparent material forming the anode 25'. The anode 25' then carries the phosphor layer 24' on the inside. The anode is made from e.g. *ITO, (indium thin oxide)*. To establish direct electrical contact with the anode 25', conductive fingers can be arranged as mentioned above and some regions of the anode 25' are therefore not covered with phosphor. Alternatively, electrically conductive surfaces being in contact with the anode can be applied on to the phosphor layer. Those surfaces are small not to interfere with the operation of the light source but of sufficient size to establish electrical contact with the conductive fingers.

The operation of this embodiment illustrated in figure 4 is essentially the same as that of the embodiment illustrated in figure 2. However, after leaving the cathode 40, the electrons will first hit the phosphor layer and excite it to luminescence, and thereafter they will be drained off by the anode. Since the electrons first hit the phosphor layer and do not have to pass through the anode layer before they hit the phosphor layer, the voltage applied between the cathode and the anode can be about 1-2 kV lower than in the embodiment illustrated in figure 2.

In the previous embodiments, the cathode 40 has been shown to be arranged concentrically with the container wall 20. However, it can be non-concentrically arranged as shown in figure 5. Here the center of the cathode 40 is located at a distance d from the center²⁶ of the cylindrical container wall 20. By this arrangement, the electric field will be increased at portions of the container and decreased in other portions. Hereby a possibility to control the light intensity is obtained, so that increased light intensities can be achieved in certain directions. However, the electric field around the cathode, the extraction field, will not be substantially changed due to the non-concentricity for moderate distances d . If the inner diameter of the cylinder wall 20 is 20 mm and the outer diameter of the cathode is 2 mm, a distance d of 5 mm will cause higher current densities at the portions of the cylinder wall closest to the cathode 40, but the electric field around the cathode will still be sufficient for field emission around the cathode 40. For small distances d (e.g. around 0.1 mm) the effects are almost none. This means that exact concentricity is not necessary for obtaining homogenous light emission.

In figure 6, a further embodiment of the invention is shown, where the cathode 40, i.e. the carrier (wire or rod) of the surface irregularities (the nanotubes), have a non-circular cross section. The cross section shown is elliptical, but could

corners. In this case the electric field, the current densities and the light intensities can be controlled in a similar manner as in the previous embodiment of figure 5.

5 In earlier embodiments the container has been shown to be a straight cylinder. However other shapes are possible. In figure 7 a container having the shape of a bent tube, is shown. The tube can be bent in a circular form or semi-circular, as shown.

10 Since nanotubes are conductive the core or carrier (the wire or rod) of the cathode 40 does not have to be conductive. It can be made of a semi-conductive or an insulating material. In such a case the nanotubes are applied in a continuous layer, and electrical connections are provided to this layer. This is
15 valid for all previous embodiments.

In the embodiments above a phosphor layer and an anode layer have been employed. However, using a conductive phosphor, this layer can also serve as anode, and the special anode layer can
20 be omitted.

Although the invention is described by way of the above examples, naturally, a skilled person would appreciate that many other variations than those explicitly disclosed are
25 possible within the scope of the claims.

It should be noted that although the embodiments include certain details for the electrical connection and for the support of the parts in the light source, those can be formed in many other ways, as appreciated by a person skilled in the art, and do not limit the scope of invention.
30

CLAIMS

1. A light source, comprising an evacuated container having walls, at least a portion of which comprises an outer glass layer (23, 23') which on at least part thereof is coated on the inside with a layer of phosphor (24, 24') forming a luminescent layer and a conductive layer (25, 25') forming an anode, which layer of phosphor (24, 24') is excited to luminescence by electron bombardment from a field emission cathode (40, 40') located in the interior of the container, characterised in that
 - the field emission cathode (40, 40') comprises an elongate wire-shaped carrier having a cylindrical surface and a diameter in the range 0.5-5 mm, and
 - at least a portion of said cylindrical surface being provided with conductive surface irregularities in the form of tips, having a radial extension being less than about 10 μ m.
2. The light source according to claim 1, wherein the elongate carrier is made of a conductive material.
3. The light source according to claim 1, wherein the elongate carrier is made of a semi-conductive material.
4. The light source according to claim 1, wherein the elongate carrier is made of an insulating material.
5. The light source according to any of claims 1-4, wherein the container has a cylindrical shape and a diameter in the range 8-80 mm.
6. The light source according to any of claims 1-5, wherein the elongate carrier is coaxially arranged in the container.
7. The light source according to any of claims 1-5, wherein the carrier is eccentrically arranged in the container.

8. The light source according to any of claims 1-7, wherein
 - the elongate carrier has an essentially circular cross section.

5

9. The light source according to any of claims 1-7, wherein
 - the elongate carrier has a non-circular cross section with a smooth curve, e.g.elliptical.

10

10. The light source according to any of claims 1-9, wherein
 - the elongate carrier comprises a wire.

11. The light source according to any of claims 1-9, wherein
 - the elongate carrier comprises a rod.

15

12. The light source according to any of claims 1-11, wherein
 - the tips have a radius of curvature being in the range 0.1-100 nanometers.

20

13. The light source according to any of claims 1-12, wherein
 - the elongate carrier has a first longitudinal axis,
 - the cylindrical surface is at least partially covered with carbon nanotubes, each having a second longitudinal axis being essentially perpendicular to the first longitudinal axis, and
 - free ends of said nanotubes constitute said tips.

25

30

14. The light source according to claim 13, wherein said nanotubes are arranged on the carrier in the form of a deposited nanotube film.

35

15. The light source according to any of claims 1-14, wherein the tips are essentially uniformly distributed around the carrier.

16. The light source according to any of claims 1-15, wherein
 - the luminescent layer (24) is arranged between the glass layer (23) and the anode (25) and

- the anode (25) is made of a reflective material for reflection of the light emitted from the luminescent layer (24).

17. The light source according to any of claims 1-15, wherein
- the anode (25') is arranged between the glass layer (23') and the luminescent layer (24'), and
 - the anode (25') is made of a transparent material.
-

18. The light source according to any of claims 1-15, wherein
- the phosphor layer is formed by a conductive phosphor and the phosphor layer also forms the anode.

19. The light source according to any of claims 1-18, wherein the container has the shape of a straight cylinder.

20. The light source according to any of claims 1-18, wherein the container has the shape of a curved tube, curved in e.g. a circular or semicircular curve.

21. A field emission cathode (40), for use in a light source, and to be at least partially encompassed by an anode, and comprising an elongate electrically conductive means, characterised in that

- said elongate electrically conductive means includes conductive surface irregularities in the form of tips, having a radial extension being less than about 10 μm , and being provided on at least a portion of a wire-shaped carrier having a cylindrical surface and a diameter in the range 0.5-5 mm.

22. The field emission cathode according to claim 21, wherein the elongate wire-shaped carrier is made of a conductive material.

23. The field emission cathode according to claim 21, wherein the elongate wire-shaped carrier is made of a semi-conductive

24. The field emission cathode according to claim 21, wherein the elongate wire-shaped carrier is made of an insulating material.

5

25. The field emission cathode (40) according to any of claims 21-24, wherein

- the cathode is to be at least partially encompassed by an anode having a cylindrical shape and a diameter in the range 8-80 mm.

10

26. The field emission cathode (40) according any of claims 21-25, wherein

- the elongate carrier has an essentially circular cross section.

15

27. The field emission cathode (40) according to any of claims 21-25, wherein

- the elongate carrier has a non-circular cross section with a smooth curve, e.g.elliptical.

20

28. The field emission cathode according to any of claims 21-27, wherein

- the elongate carrier comprises a wire.

25

29. The field emission cathode according to any of claims 21-27, wherein

- the elongate carrier comprises a rod.

30

30. The field emission cathode according to any of claims 21-29, wherein

- the tips have a radius of curvature being in the range 0.1-100 nanometers.

35

31. The field emission cathode according to any of claims 21-30, wherein

- the elongate carrier has a first longitudinal axis,

- the cylindrical surface is at least partially covered with carbon nanotubes, each having a second longitudinal axis being essentially perpendicular to the first longitudinal axis, and
- 5 - free ends of said nanotubes constitute said tips.

32. The field emission cathode according to claim 31, wherein
~~said nanotubes are arranged on the carrier in the form of a~~
deposited nanotube film.

10

33. The field emission cathode according to any of claims 21-32, wherein the tips are essentially uniformly distributed around the carrier.

1
2
3
4
5
6
7
8
9
10

Abstract

A light source including a field emission cathode and a field emission cathode.

5 The light source, comprises an evacuated container having walls, including an outer glass layer (23, 23') which on at least part thereof is coated on the inside with a layer of phosphor (24, 24') forming a luminescent layer and a conductive layer (25, 25') forming an anode. The phosphor (24, 24') is

10 excited to luminescence by electron bombardment from a field emission cathode (40, 40') located in the interior of the container. The field emission cathode (40, 40') comprises an elongate wire-shaped carrier having a cylindrical surface and a diameter in the mm range. At least a portion of said

15 cylindrical surface is provided with a conductive layer having surface irregularities in the form of tips, having a radial extension being less than about 10 μm . Due to the geometry and the tips, the electric field is concentrated and amplified at the field emission surface.

9
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175

1/1

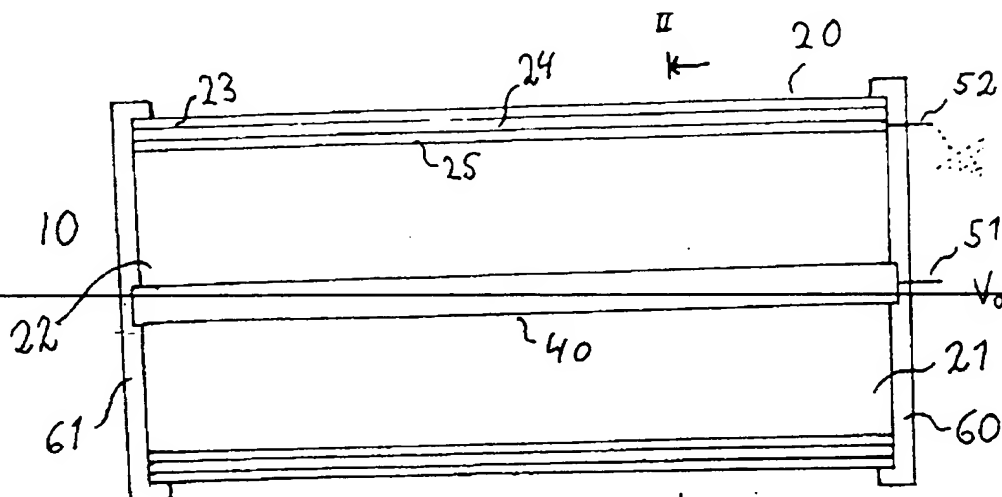


Fig. 1

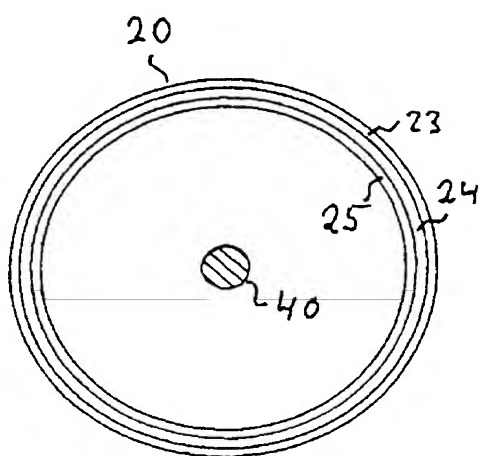


Fig. 2

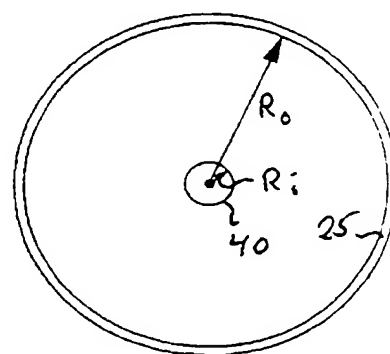


Fig. 3

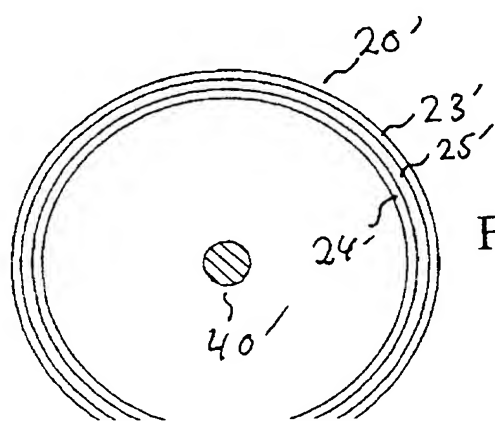


Fig. 4

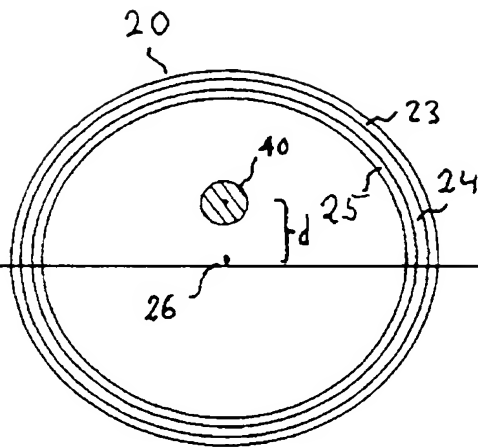


Fig. 5

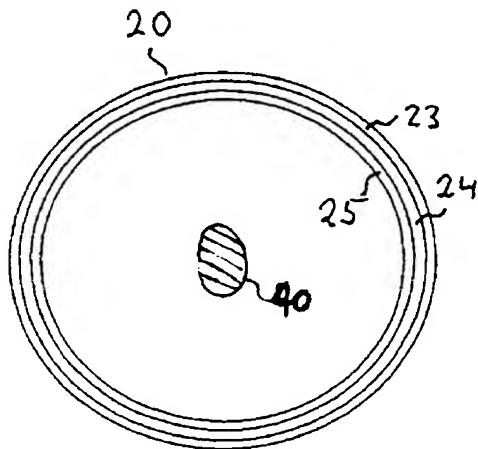


Fig. 6

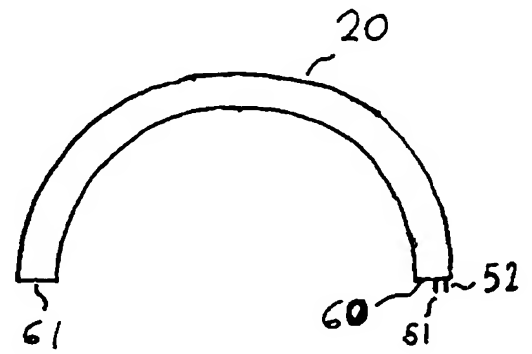


Fig. 7

99-09-10